10071

DRAFT

Ilmenite Basalt (high K)

189.5 grams

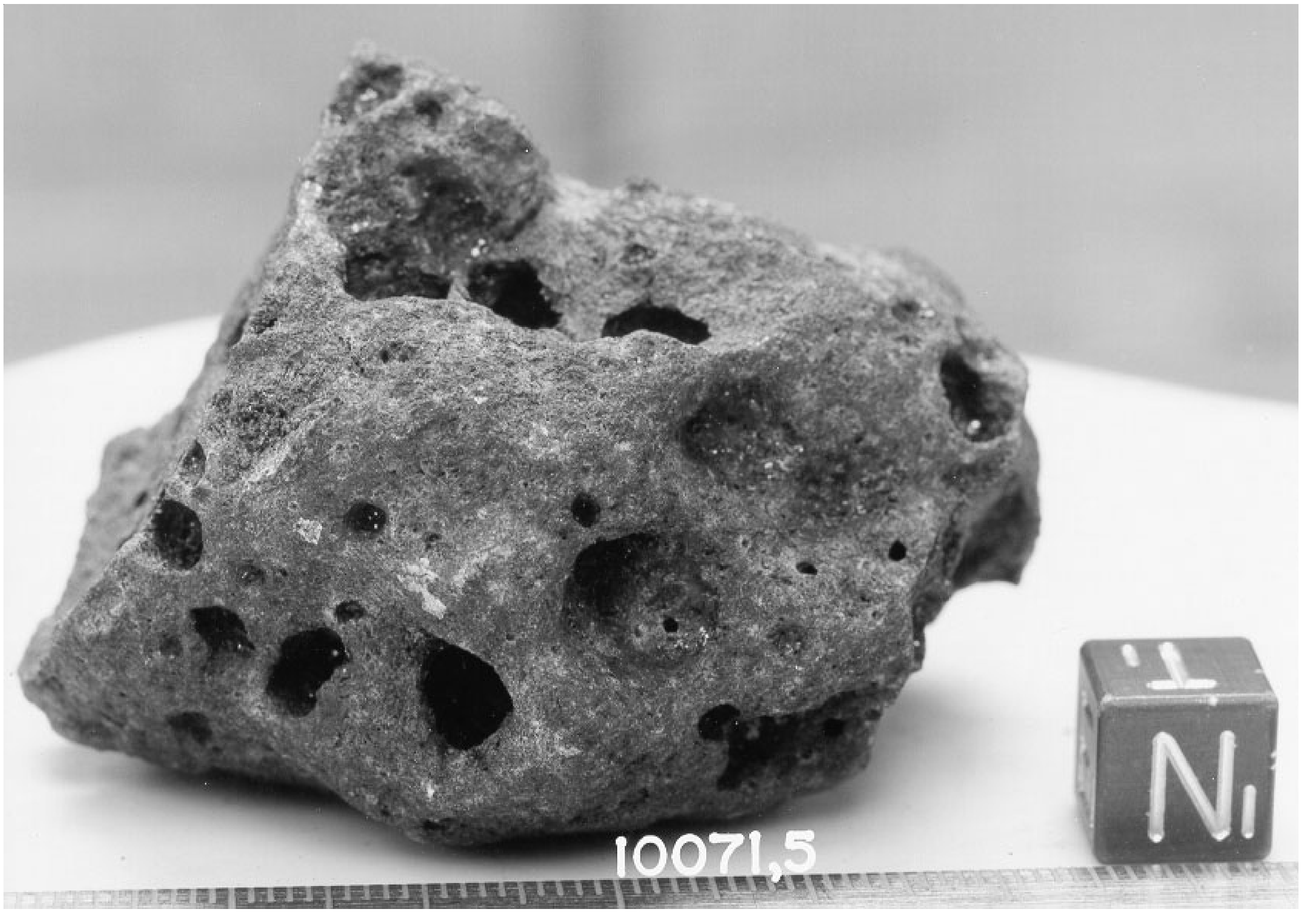


Figure 1: Photo of 10071,5 illustrating large vesicles and smooth surface, rounded by micrometeorite bombardment. NASA S76-22608. Cube is 1 cm.

Introduction

10071 is a high titanium basalt with up to 15 % ilmenite and with the new mineral armalcolite. It has prominent vesicles up to 1 mm (figure 1). The exposed surface is rounded by micrometeorite bombardment.

A very significant feature of this rock, not generally seen in Apollo samples, is the apparent igneous contact between to regions with different texture and different composition (figure 2).

10071 has been measured to be 3.68 b.y. old and has been exposed to cosmic rays for ~370 m.y.

Petrography

Schmitt et al. (1970) termed 10071 as a "fine-grained, vesicular to vuggy, plumose basalt." James and Jackson (1970) described the texture as "intersertal".

Drake and Weill (1971) found that there were two distinct basalt lithologies separated by a distinct boundary. The finer-grained portion has a variolitic texture with acicular intergroths of fine clinopyroxene and plagioclase. In this fine-grained portion the pyroxene exhibits extreme Fe-enrichment all the way to pyroxferroite (figure 4). Beaty and Albee (1978) termed the fine-grained portion "Iota" and studied it separately.

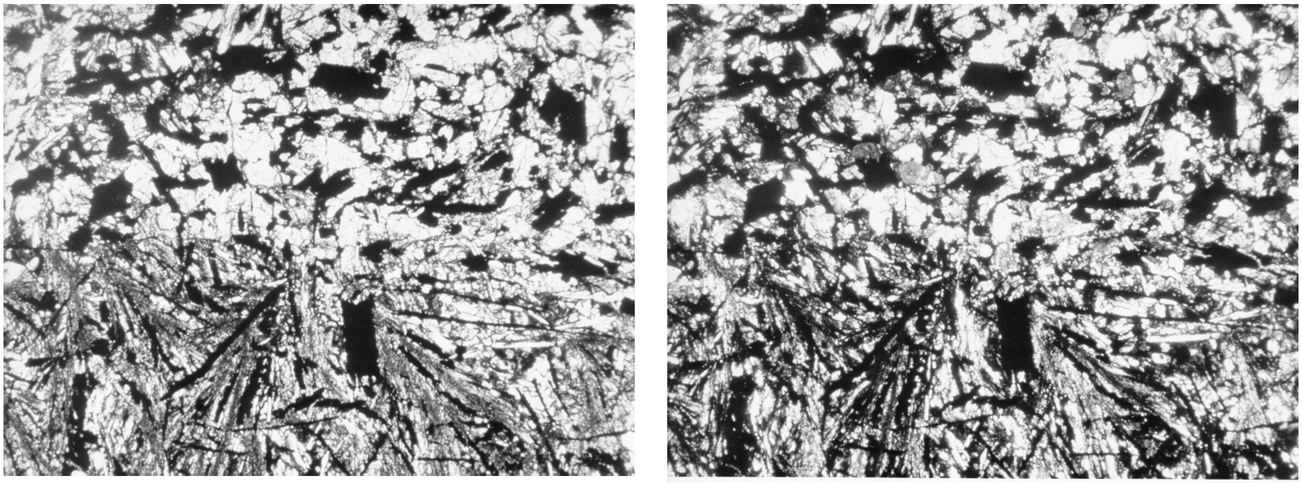


Figure 2: Photomicrographs of thin section of 10071 showing distinctly different fabric (with plane-polarized light, left and crossed Nicols, right). Scale is 2.5 mm. NASA S70-17978 and 979.

Roedder et al. (1970) studied melt inclusions in minerals in 10071 and discussed liquid immiscibility.

Mineralogy

Olivine: Minor olivine occurs as cores in large pyroxene grains where it is found to be Mg-rich,

Pyroxene: Pyroxenes are chemically zoned (Drake and Weill 1971, Beaty and Albee 1978)(figures 3 and 4).

Plagioclase: Plagioclase (An_{70-80}) is found to be non-stoichiometric, with excess silica (Drake and Weill 1971, Beaty and Albee 1978). Stewart et al. (1970) and Appleman et al. (1971) determined crystallographic data.

Ilmenite: Haggerty et al. (1970) and Drake and Weill (1971) give the analysis of ilmenite (with ~2% MgO). Stewart et al. (1970) determined crystallographic data.

Armalcolite: Haggerty et al. (1970) dertermined an opaque phase as "magnesian ferro pseudobrookite" and gave an analysis (table 2). The phase was determined to be a new mineral and was named armalcolite in honor of the crew of Apollo 11 (Armstrong, Aldrin and Collins). Anderson et al. (1970) fully discuss armaloclite. Several large grains of armalcolite were found mantled by ilmenite (Beaty and Albee 1978).

Apatite: Drake and Weill (1971) determined REE in apatite in 10071.

Chemistry

Tatsumoto et al. (1970) and Rosholt and Tatsumoto (1970) found 10071 had high U = 0.873 ppm, such that Compston et al. (1970) correctly assigned it to the high K group of Apollo 11 basalts. Ehmann et al. (1975) re-determined Zr and Hf (562 and 16.6 ppm respectively).

The chemical composition of "Iota" (Beaty and Albee 1978) is the same as that measured on the fine-grained portion (Drake and Weill 1971), and is distinct from

Mineralogical Mode for 10071

	James and Jackson 70	Beaty and Albee 1978	Drake and Weill 1971	Haggerty et al. 1970
Olivine	1.7	1.3	1.0	
Pyroxene	51.5	47.8	53.5	58.3
Plagioclase	20.6	23.6	23.5	21.7
Ilmenite	16.8	14.8	15.5	14.7
mesostasis	6.2	9.6	6.5	2.7
silica	2.8	2.2	0.5	0.8
troilite	0.1	0.44		
phosphate	tr.	0.24		

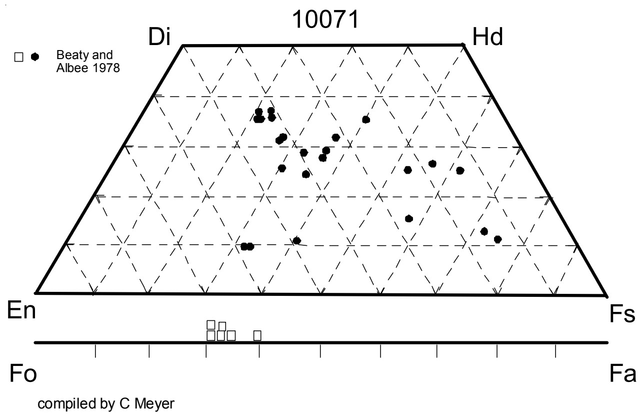


Figure 3: Pyroxene diagram for main part of 10071 (data replotted from Beaty and Albee 1978).

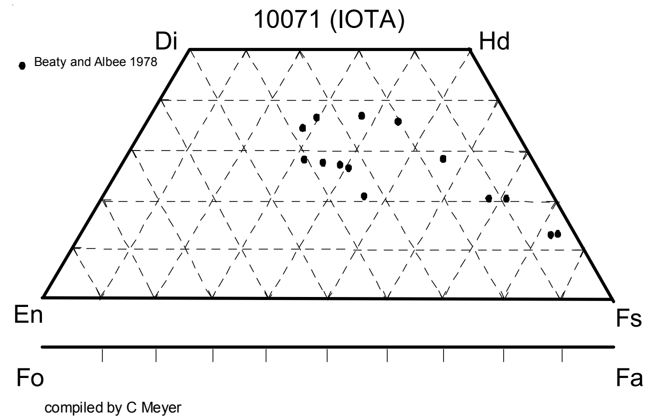


Figure 4: Pyroxene diagram for fine-grained part of 10071 (data replotted from Beaty and Albee 1978).

the coarse-grained portion of the rock. The trace element content of "Iota", has not been determined.

Radiogenic age dating
Papanastassiou et al. (1970) determined the Rb/Sr isochron age of 3.68 b.y. for 10071. The K/Ar age of the whole rock was determined as 2.88 b.y. and for the plagioclase was 3.35 b.y. by Eberhardt et al. (1974). Stettler et al. (1973, 1974) determined 3.51 b.y. by the Ar/Ar plateau technique (figure 7) and noted that data for plagioclase gave the best plateau.

Cosmogenic isotopes and exposure ages
Marti et al. (1970) and Eberhardt et al. (1974) determined the ^{83}Kr exposure age for 10071 as 372 ± 22 and 350 ± 15 m.y. respectively. Srinivasan (1974) used the Xe data of Marti et al. (1970) and Eberhardt et al. (1974) to calculate 212 and 300 m.y. exposure ages for 10071. Stettler et al. (1973, 1974) and Guggisberg et al. (1979) reported ^{38}Ar cosmic ray exposure ages of ~380 m.y. and 370-430 m.y. respectively.

Mineralogical Mode for "Iota"

	Beaty and Albee 1978	Drake and Weill 1971
Olivine	absent	0
Pyroxene	40.7	44.5
Plagioclase	36.3	35.5
Ilmenite	6.3	4.0
mesostasis	11	8.5
silica	5	7.5
troilite	0.4	
phosphate	0.34	

Other Studies
Oxygen isotopes were reported for mineral separates of 10071 by Onuma et al. (1970).

The concentrations of Sm, Nd, Lu and Hf and the isotopic ratios of $^{143}Nd/^{144}Nd$ and $^{176}Hf/^{177}Hf$ were determined by Unruh et al. (1984). Eugster et al. (1970) determined the isotopic composition of Gd.

The rare gas component of 10071 was determined by Funkhouser et al. (1970), Pepin et al. (1970), Marti et al. (1970), Bogard et al. (1971) and Eberhardt et al. (1970, 1974).

Processing
Apollo 11 samples were originally described and cataloged in 1969 and "re-cataloged" by Kramer et al. (1977). In 2005, a portion of this sample was presented to Neal Armstrong as part of the Astronaut Ambassador Program for public display at a museum of his choosing.

List of Photo #s for 10071

S69-47614
S69-47288 – 289 PET B&W
S69-47292 – 297
S69-47304 – 309
S69-47353 – 359
S70-17978 – 979 TS
S70-48981 – 982 TS
S76-22602 – 609 ,5
S76-23372 – 373 ,11
S76-26082 – 083 ,13
S76-26321 – 322 TS B&W

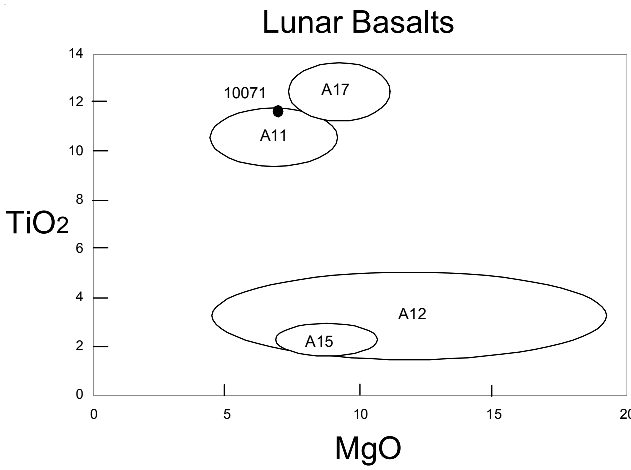


Figure 5: Composition of 10071 compared with that of other Apollo lunar samples.

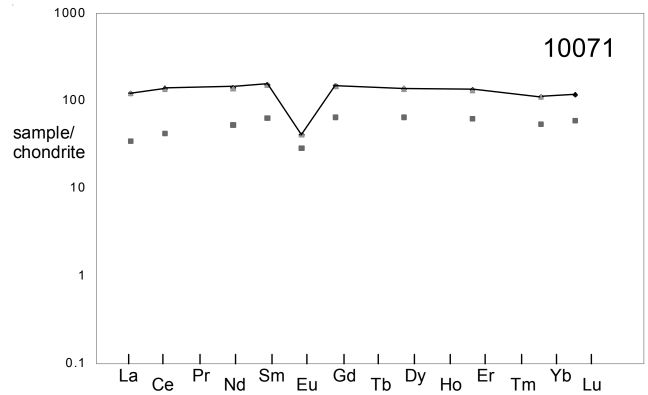
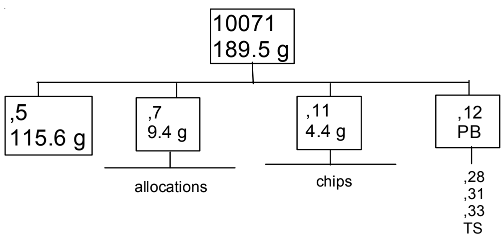


Figure 6: Normalized rare-earth-element composition for high-K basalt 10071 (the line) compared with that of low-K basalt 10020 and high-K basalt 10049 (the dots) (data from Wiesmann et al. 1975).



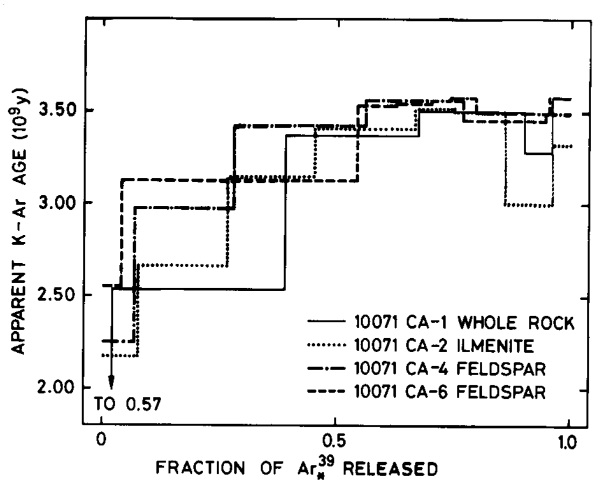


Figure 7: Argon relase curves for mineral separates from basalt 10071 (from Stettler et al. 1973). The plagioclase separate gave the "best" plateau age = 3.51 +/- 0.06 b.y.

Table 2. Chemical composition of armalcolite.

reference	Beaty78	Anderson70	Haggerty70	
weight				
SiO2 %	0.11			(a)
TiO2	73.15	73.4	73.4	(a)
Al2O3	1.57	1.62	1.62	(a)
FeO	15.51	15.3	15.3	(a)
MnO	0.01	0.08	0.08	(a)
MgO	7.66	7.7	7.7	(a)
CaO		0.01	0.01	(a)
Cr2O3	2.02	2.15	2.15	(a)

tech: (a) emp

Summary of Age Data for 10071

	Rb/Sr	Ar/Ar (plag)	K/Ar
Papanastassiou et al. 1970	3.68 ± 0.02 b.y.		
Stettler et al. 1973		3.51 ± 0.06	
Eberhardt et al. 1974			2.88 ± 0.06
Wanless et al. 1970			2.875

Note: Ages not corrected for new decay constants.

Table 3	U ppm	Th ppm	K ppm	Rb ppm	Sr ppm	Nd ppm	Sm ppm	technique
Tatsumoto et al. 1970	0.873	3.43						IDMS
Rosholt and Tats 1970	0.873							
Wanless et al. 1970			2574	5.88	170.6			
Goles et al. 1970							20	INAA
Annell and Helz 1970				5.2				
Gast 1970			2770	5.93	161	64.5	22.7	IDMS
Rhodes 1980		3.4		5.6	165		19.5	INAA
Unruh et al. 1984						61.5	20.9	INAA
Papamastassiou 70				5.82	165			IDMS

Table 1. Chemical composition of 10071.

reference	Gast70		Wiesmann75		Goles70		Rhodes80		Annell70		Drake 71			Beaty78	
weight											coarse	fine-grained		“Iota”	
SiO2 %					40.86	(c)	40.51	(d)			42.2	46.9	(f)	47.89	(g)
TiO2	13.8				11.7	(c)	11.87	(d)			10.2	4.8	(f)	5.75	(g)
Al2O3					8.22	(c)	7.91	(d)			9.7	14.5	(f)	11.29	(g)
FeO					19.17	(c)	19.65	(d)			16.5	15.4	(f)	17.56	(g)
MnO					0.21	(c)	0.25	(d)	0.29	(e)				0.22	(g)
MgO					7.29	(c)	7.51	(d)			7.7	3.3	(f)	4.69	(g)
CaO	10.9				10.07	(c)	10.48	(d)			11.3	10.8	(f)	10.87	(g)
Na2O	0.52	(a)	0.52	(a)	0.49	(c)	0.53	(c)			0.64	0.66	(f)	0.8	(g)
K2O	0.33	(b)	0.33	(b)			0.3	(d)			0.44	1.02	(f)	0.42	(g)
P2O5							0.22	(d)						0.16	(g)
S %														0.25	(g)
sum															
Sc ppm					73.2	(c)	78	(d)	97	(e)					
V					92	(c)			78	(e)					
Cr					2170	(c)	2450	(c)	3060	(e)					
Co					27.1	(c)	25.4	(d)	33	(e)					
Ni									7	(e)					
Cu					11	(c)			14	(e)					
Zn															
Ga							8.8	(d)	4.8	(e)					
Ge ppb															
As															
Se															
Rb	5.93	(b)	5.93	(b)			5.6	(d)	5.2	(e)					
Sr	161	(b)	161	(b)			165	(d)	140	(e)					
Y							166	(d)	162	(e)					
Zr					210	(c)			644	(e)					
Nb									24	(e)					
Mo															
Ru															
Rh															
Pd ppb															
Ag ppb															
Cd ppb															
In ppb															
Sn ppb															
Sb ppb															
Te ppb															
Cs ppm	0.17	(b)	0.17	(b)											
Ba	327	(b)	327	(b)	450	(c)			470	(e)					
La	28.8	(b)	28.8	(b)	25.8	(c)	24.1	(c)	27	(e)					
Ce	83.5	(b)	83.5	(b)	84	(c)	75	(c)							
Pr															
Nd	64.5	(b)	64.5	(b)											
Sm	22.7	(b)	22.7	(b)	20	(c)	19.5	(c)							
Eu	2.32	(b)	2.32	(b)	2.12	(c)	2.03	(c)							
Gd	29.3	(b)	29.3	(b)											
Tb					5.7	(c)	4	(c)							
Dy	33.5	(b)	33.5	(b)											
Ho					9.2	(c)									
Er	21.3	(b)	21.3	(b)											
Tm															
Yb	20.5	(b)	18.2	(b)	20.8	(c)	16.2	(c)							
Lu	2.87	(b)	2.87	(b)	3.08	(c)	2.33	(c)							
Hf					19.1	(c)	15.9	(c)							
Ta					2	(c)	2.7	(c)							
W ppb															
Re ppb															
Os ppb															
Ir ppb															
Pt ppb															
Au ppb															
Th ppm							3.4	(d)							
U ppm					0.69	(c)									

technique: (a) AA, (b) IDMS, (c) INAA, (d) XRF, (e) emission spec., (f) emp, (g) modal